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REGIONAL CHARACTERISTICS OF SEVERE SUMMER HAILSTORMS IN ILLINOIS

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Introduction

Certain regional characteristics of the 128 most severe summer hailstorm days in Illinois (1910-1959 period) have been investigated. With U. S. Weather Bureau data for Iowa and Missouri in conjunction with similar data for Illinois, many of the time and space characteristics of these June-August hailstorms have been analyzed for the 3-state area. On 88 percent of the severe hailstorm days in Illinois, hail occurred very near to the borders of either Missouri or Iowa, and information was desired as to the area of origin of these hailstorms. From the data available, efforts were made to identify 1) regional variations in the origin area of these severe hailstorms, 2) their durations in time, 3) the areal extent, 4) the direction of storm movement, and 5) the relationship of these factors with synoptic conditions.

Occurrences of widespread and/or severely damaging summer hailstorms in Illinois have been previously identified, and their characteristics were discussed in two earlier research reports to the Crop-Hail Insurance Actuarial Association. [1, 2] In Research-Report No. 5, all summer days during the 1910-1959 period in which four or more Weather Bureau stations reported hail were identified as "widespread hailstorm days". [1] This

definition delineated 113 such hailstorm days in the 50-year period. Research Report No. 4 identified the 50 summer hailstorm days that caused the greatest monetary losses in Illinois during the 1915-1959 period. [2] A total of 35 of these damaging storm days also were among those 113 dates classified as widespread hailstorm days. The remaining 15 damaging hailstorm days and the 113 widespread hailstorm days (which included 35 of the damaging hailstorm days) were combined to furnish a total of 128 severe summer hailstorm days in the 1910-1959 period. These 128 hailstorm days are hereafter referred to in this report as severe summer hailstorm days in Illinois.

Data

To perform a climatological analysis of hail frequencies, hail data for 240 Weather Bureau stations in Iowa and Missouri were, procured in 196l. [3] From these data all the Iowa and Missouri stations were listed with occurrences of hail 1) on the dates of the 128 severe hailstorms in Illinois and 2) on the dates prior to the 128 storm dates. These stations along with their time of occurrence data, if available, were plotted on individual storm maps for each storm date, and these maps also displayed similar hail data available for Illinois. The Illinois hail data were derived from 134 stations and from other sources described in previous reports. [1, 2] Synoptic conditions, determined from northern hemisphere synoptic weather maps and U.S. Weather Bureau daily weather maps, and storm movements

relating to the hail occurrence were also noted on these maps.

Method of Analysis

Weather Bureau stations in the 3-state area are normally separated by distances ranging from 20 to 30 miles resulting in a density of observations which will not allow any high degree of areal accuracy in defining hailstorm origin, continuity, extent, movement, or duration. Measurements of these characteristics have been made for most of the storm days, but these measurements must be considered as approximations.

To this end, measurements of the extent of hail occurrences were expressed as the number of Weather Bureau areal divisions[4,5,6] containing hail occurrences (Fig. 1). The average size of these 24 divisions in the 3-state area is approximately 6500 square miles. The locations of the Illinois hailstorm origins, as based upon consideration of the temporal and storm continuity data, were identified by occurrence within these same divisions (Fig. 1). In defining an origin occurrence and storm continuity, all distinctively separate groups of hail reports, as based on regional and temporal data, were identified as "hail areas," and origins were determined for all "hail areas." On many storm days 2 or more such areas occurred.

Continuity in the movement of 1 or more hailstorm areas along a given track or line of activity was identified when most stations with hail in Iowa and Missouri were aligned, on a temporal and regional basis,

with stations with hail in Illinois. In Figure 2a, an example of this continuity-definition is illustrated by arrows connecting the locations of hail reports. Temporal data were found to be too sparse to permit an accurate hourly analysis of the time of storm occurrence. Consequently, storm durations were determined for 12-hour increments of time. The general direction of hailstorm movement was identified by the alignment of stations, sequence of reports, and by considering the synoptic conditions associated with the storms. Another measure of hail extent and continuity was obtained by examining the frequency of station reports for each hailstorm day.

Results of Analysis

Synoptic Conditions. The basic types of synoptic conditions deemed responsible or at least directly associated with the hail incidence on each of the 128 hailstorm days in. Illinois were studied. The types had been previously identified in performing research leading to the preparation of earlier reports. [1, 2] The synoptic conditions associated with the 128 storm days were grouped into four basic types which were cold frontal (including pre-frontal), stationary or warm frontal (including pre-frontal), warm air mass, and surface lows or troughs. The cold front and stationary-warm front conditions accounted for 82 percent of the total days.

Another analytical description obtained for days with severe hail-storms in Illinois was strongly related with the synoptic conditions., The cartographic analysis of each storm included the plotting of hail incidences

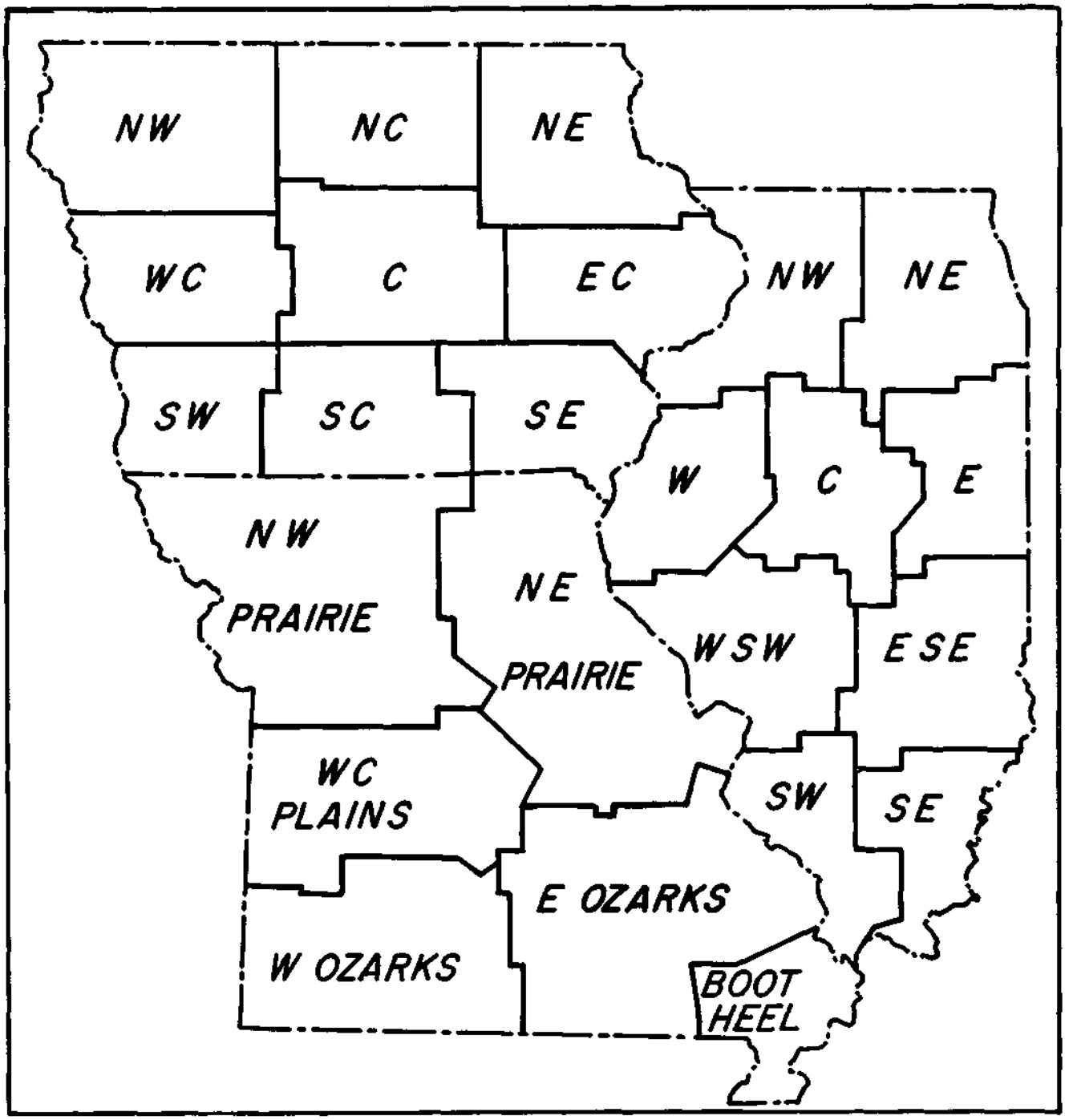


FIG. I U.S. WEATHER BUREAU DIVISIONS IN ILLINOIS, IOWA, AND MISSOURI

on the day prior to the date of the Illinois hailstorm. Inspection of these

TABLE 1

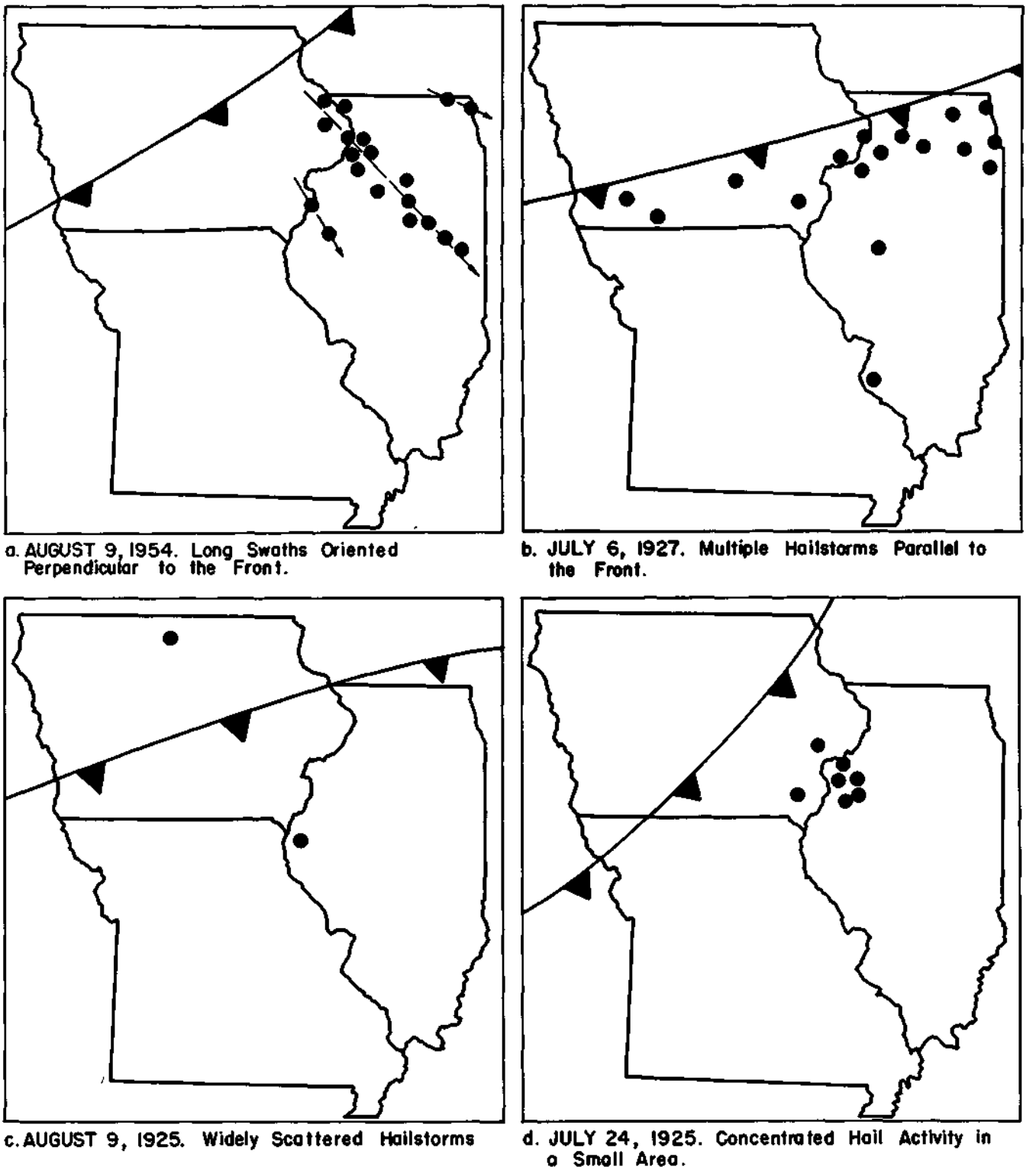
SYNOPTIC CONDITIONS ASSOCIATED
"WITH SEVERE HAILSTORM DAYS IN ILLINOIS

	Synoptic conditions				
	Cold Fronts	Stationary-Warm Front	Warm Air Mass	Lows-Trough	Total
Number of severe hail days	75	29	17	7	128
Percent of total hail days	59	23	13	5	100
Number of days when reformation occurred	40	14	4	6	64

data and the corresponding synoptic analysis for each map revealed that on 64 storm days, or 50 percent of the total, the hailstorms occurring in Illinois were actually a reformation of a hail-producing system which had been in existence earlier in Iowa or Missouri, but had quit producing hail-storms for a period of 12 hours or longer. (A typical example of the reformation-type hail system is shown in Figure 6d.) As shown in Table 1, 40 of these 64 days of storm reformation were associated with cold frontal conditions. Six of the seven hail days caused by lows-troughs were cases of storm reformation in Illinois. The 40 cases represented 53 percent of the total number of cold frontal conditions which produced severe summer hailstorm days in Illinois. Thus, hailstorms on one-half of all severe Illinois hailstorm

days actually represent only a portion of the total hailstorms produced by major synoptic systems which had produced hailstorms elsewhere in the Middle West in periods more than 12 hours prior to the Illinois storms.

In Figures 2 and 3, typical examples of hail patterns associated with the various synoptic conditions are portrayed. The analysis of the 75 cold-front severe hail days revealed that there were four different but readily identifiable hail patterns found repeatedly on the plotted maps. Huff[1] identified the two most frequent patterns of storms with cold fronts, and examples of these are shown as Figures 2a and 2b. One of these patterns consists of one or more long swaths perpendicular to and moving away from the front (Fig. 2a). The other basic pattern is a multiple outbreak along and parallel to the front (Fig. 2b). Figure 2c shows a typical pattern found on a day with only two widely separated hailstorm reports; however, this particular day was ranked, based on monetary losses, as the 15th most damaging hail day in, Illinois. [2] Figure 2d shows a fourth type of pattern found for several of the storm days associated with cold fronts. In this type, the area of hail experience was relatively small, but almost all of the stations in the hail area reported hail. In Figure 3, examples of hail patterns typical of the other synoptic types are shown. As shown in Figures 3a and 3b, hail occurrences with warm and stationary fronts were often widely scattered but frequently assumed a pattern with a semblance of an east-west orientation.



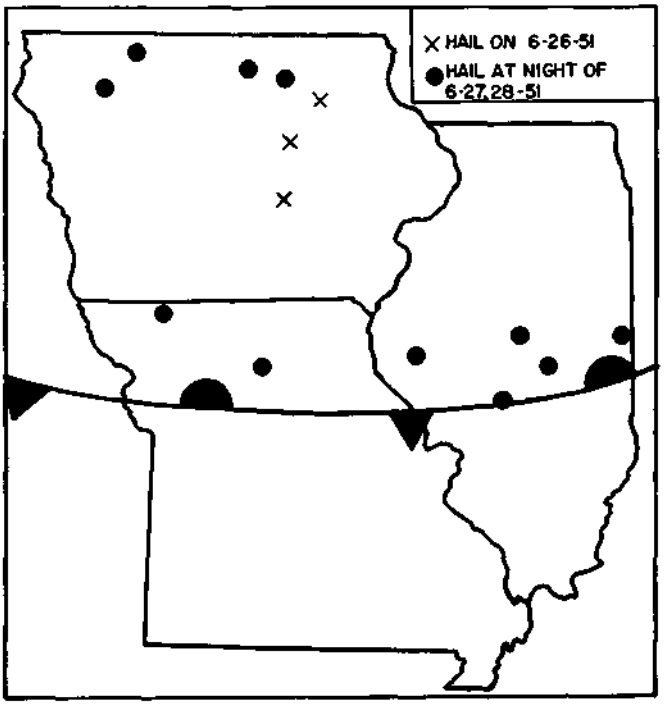
a. AUGUST 9, 1954. Long Swaths Oriented Perpendicular to the Front.

b. JULY 6, 1927. Multiple Hailstorms Parallel to the Front.

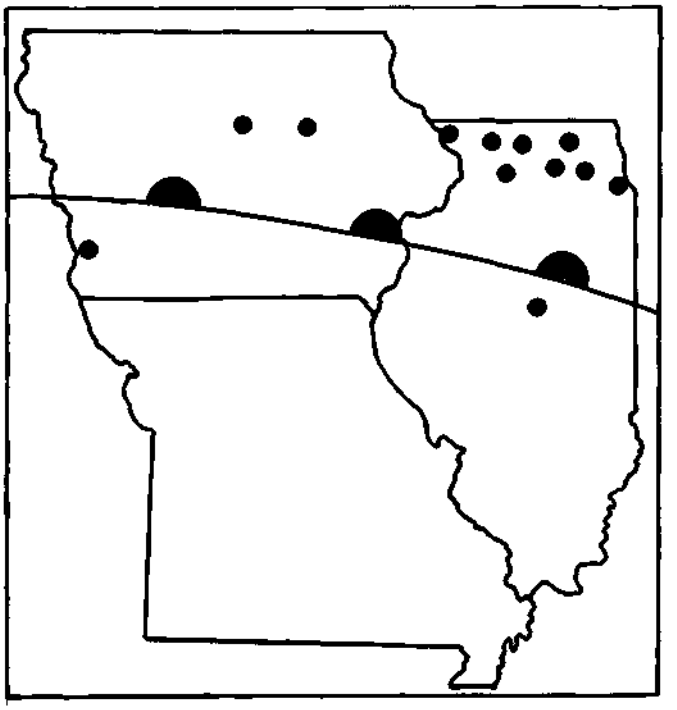
c. AUGUST 9, 1925. Widely Scattered Hailstorms

d. JULY 24, 1925. Concentrated Hail Activity in a Small Area.

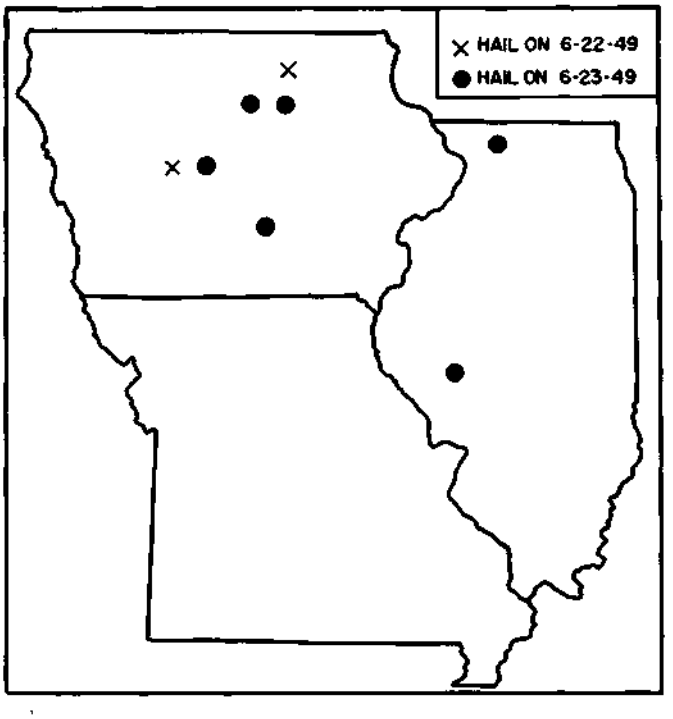
FIG. 2 EXAMPLES OF TYPICAL HAIL PATTERNS ASSOCIATED WITH COLD FRONTS



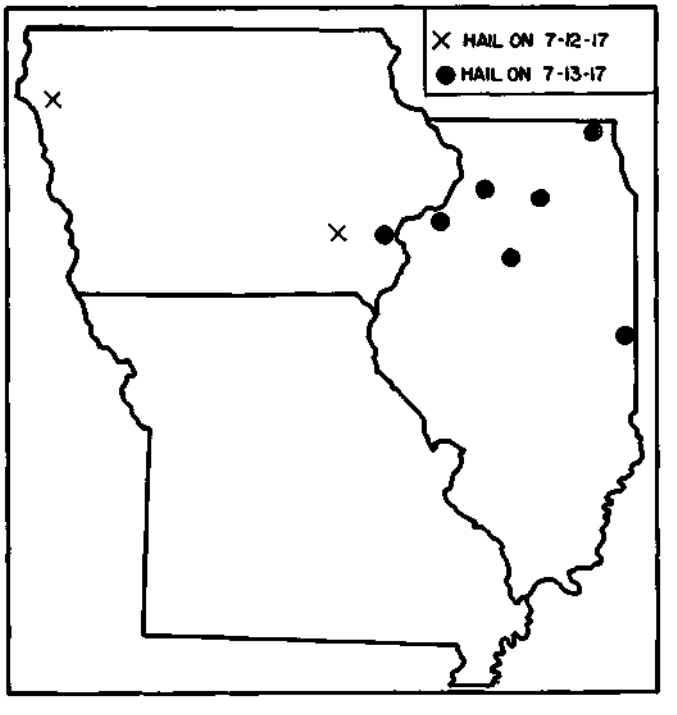
a JUNE 27, 1951. Stationary Front



b JULY 1-2, 1933. Warm Front



c. JUNE 23, 1949. Warm Air Mass Conditions



d JULY 13, 1917. Surface Low Pressure Passage

FIG.3 EXAMPLES OF TYPICAL HAIL PATTERNS WITH VARIOUS SYNOPTIC CONDITIONS

Origin Areas. The number of times a distinctly separate hail area originated in each of the 24 divisions (Fig. 1) was counted. Gn most of the severe hailstorm days separate hail areas formed in 2 or even 3 separate divisions. Only one origin division was identified for 55 of the severe summer hail days. Consequently, the total count of origins was 231. The frequency of origins per state division is displayed in Figure 4. The three westernmost divisions in Illinois were the preferred areas for hail area origins with a combined total of 96 origins, or about 42 percent of the total originations. The fourth and fifth ranked divisions for the formation of the hail areas were the two southeasternmost divisions in Iowa. Quite obviously, severe Illinois hailstorms in the 1910-1959 period formed most frequently along the Mississippi River Valley in the area extending northward from St. Louis to Wisconsin. The six divisions bordering this extent of the river represent about 25 percent of the area investigated, but within these divisions 145 of the origins occurred, which is 64 percent of the total formations.

The origin frequency also was examined using a synoptic analysis. The origin frequencies for cold fronts exceeded those of the other synoptic types in all 24 divisions except in NE Missouri and ESE Illinois where origins with stationary fronts predominated. Other major findings of this investigation were: 1) 75 percent of the storm origins in the E and SE Iowa divisions (Fig. 1) were associated with cold fronts; 2) 73 percent of the origins in the NE Prairie of Missouri were with stationary and/or warm fronts; 3) 65 percent of all the origins in NW Illinois were with cold fronts;

4) 50 percent of all origins in WSW Illinois were with lows, stationary fronts, or warm air masses; and 5) 33 percent of the origins in the SW Illinois area were with warm air mass conditions. In general, the formations or origins of hailstorms in the portion of the Mississippi Valley area where Illinois and Iowa adjoin were largely associated with cold frontal conditions, whereas in the valley area where Missouri and Illinois adjoin the stationary-warm front conditions were the conditions most frequently associated with storm origins.

Another indication of the location of storm origin areas is furnished by other areal data recorded during the analysis. The number of times that hail was reported in Illinois within 30 miles of the Mississippi River also was recorded. It was found that on 113 of the 128 severe hailstorm days, some of the hail in Illinois occurred somewhere within 30 miles of the western boundary of Illinois. This analysis further indicated that the severe hailstorms which occurred in Illinois frequently originated within or relatively near to the main Mississippi River Valley. These findings are discussed more fully in the next section of this report. The information on storm reformation also indicated that 50 percent of the origins recorded in this area were likely . unique to the area and.were not cases of reformation ofyhailstorms by conditions which had produced hail earlier in Iowa or Missouri.

Movement and Continuity. The general directions of movement exhibited by the hail areas on each storm date were calculated, and an average or preferred direction of movement for the day was determined. On 37 of the 128 days no direction of movement could be determined. The

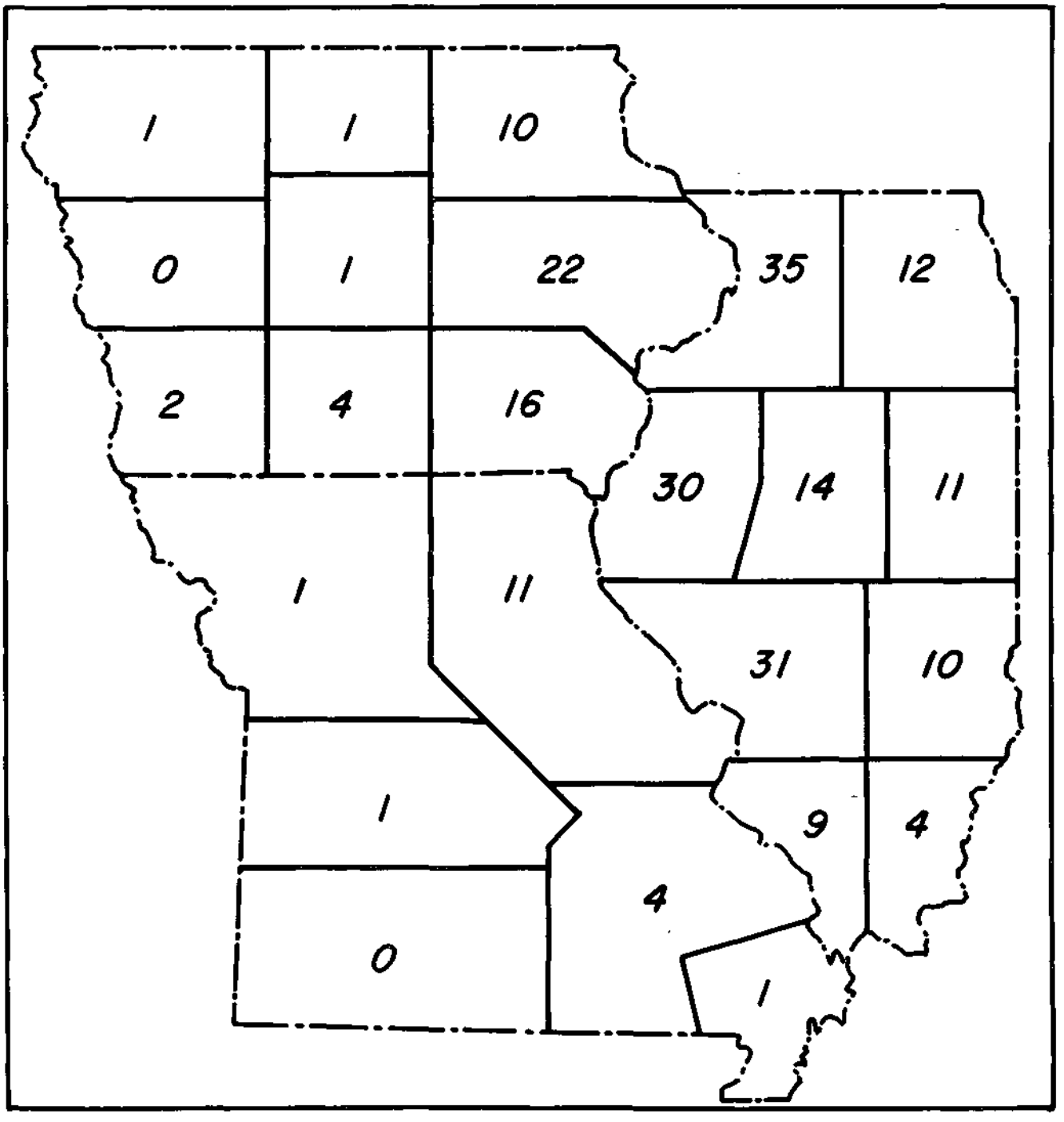


FIG.4 NUMBER OF TIMES HAIL ORIGINATED IN VARIOUS STATE DIVISIONS

frequency of movements according to synoptic type are shown in Table 2. No significant variations in movement according to synoptic typing are apparent although most movements from the NNW were with cold fronts. The totals reveal that movement from the NW and WNW accounted for 63 percent of the total known movements.

TABLE 2

DIRECTION FROM WHICH HAIL AREAS MOVED ON SEVERE HAIL DAYS IN ILLINOIS, SORTED AGCORDING TO SYNOPTIC TYPES

Synoptic types	Number of movements from each direction								
	NNW	NW	WNW	W	WSW	SW	SSW	Unknown	Total
Cold Fronts	10	27	14	6	3	2	0	13	75
Stationary-Warm Fronts	2	5	4	4	1	1	1	11	29
Air Mass	0	1	4	1	1	0	0	10	17
Lows-Troughs	0	0	2	2	0	0	0	3	7
Totals	12	33	24	13	5	3	1	37	128

The continuity of the storms was examined in the Mississippi Valley region where the preponderance of hail origins (Fig. 4) and hail incidences (Fig. 5) occurred. It was considered of interest to determine whether the many hail incidences in Illinois near to the river represented semi-continuous storm movements from Iowa and/or Missouri. In Table 3 the number of times hail in Illinois occurred within 30 miles of the Iowa and

Missouri borders is listed by, synoptic types. On. 113 storm days hail in Illinois occurred within 30 miles of the border of one or both adjacent states, and on only 15 days no hail in Illinois occurred within this 30-mile western zone. As shown in Table 3, some of the hail occurring in Illinois was reported

TABLE 3

LOCATION OF ILLINOIS HAIL REPORTS WITH RESPECT TO IOWA AND MISSOURI AND BY SYNOPTIC TYPES

	Number of Storm Occurrences by Synoptic Type				
Location of Illinois Hail	Cold Front	Stationary-Warm Front	Warm Air Mass	Lows-Troughs	Total
Within 30 miles of Iowa-Missouri	23	9	1	1	34
Within, 30 miles of Iowa only	33	8	5	5	51
Within 30 miles of Missouri only	12	9	6	1	28
More than 30 miles from Iowa and Missouri	7	3	5	0	15

within 30 miles of Iowa on 85 days and near Missouri on 62 days.

On each of the 113 days when hail in Illinois occurred near to either or both of these two adjacent states, the hail areas involved were examined to determine whether they were portions of semi-continuous hail paths extending from the adjacent states into Illinois. This was the method employed to obtain a measure of storm continuity and it also served as another measure

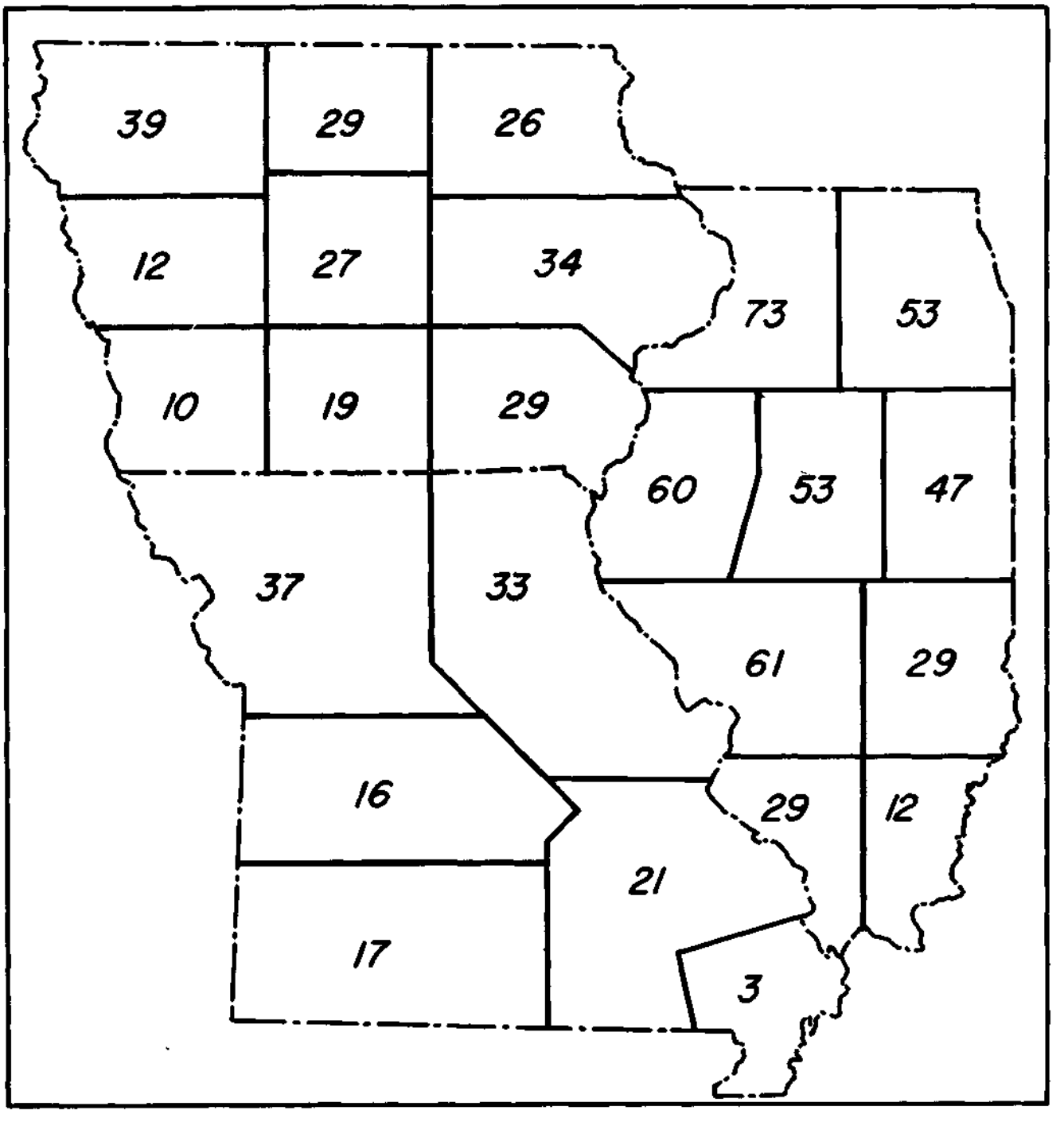


FIG. 5 NUMBER OF TIMES HAIL OCCURRED IN EACH DIVISION ON DAY PRIOR TO AND DAY WITH SEVERE HAILSTORMS IN ILLINOIS

of the areas of storm origination (see previous section).

Results presented in Table 4 reveal that a large percentage of all Illinois hail incidences which occurred near to Iowa and/or Missouri were not portions of semi-continuous hail areas which might have originated in these two states. Continuity of hailstorm areas or cells across the Mississippi valley occurred less than 50 percent of the time on days with hail in Illinois near the valley. However, continuous storm movements from Iowa were more frequent than from Missouri. These findings also

TABLE 4

SYNOPTIC CONDITIONS WHEN HAIL IN ILLINOIS (NEAR MISSOURI AND IOWA) WAS NOT A PORTION OF SEMI-CONTINUOUS STORM MOVEMENT FROM WEST

	Number of No-Movements by Synoptic Types*				
	Cold Front	Stationary-Warm Front	Air Mass	Lows-Troughs	Total
Illinois hail near Iowa	54/	53	66	83	56
Illinois hail near Missouri	69	72	86	100	72

*Expressed as percentages of total storms near these two states (Table 3).

illustrate the frequency with which Illinois storms originated in close proximity to river. On a regional basis, 72 percent of all Illinois hail near Missouri was not a portion of a continuous hail area in Missouri. More than one-half (56 percent) of the Illinois hail occurrences near Iowa were not a portion of a continuous storm track from Iowa. On 86 of the 113 days with hail near to one or both of the adjacent states, the hail in

Illinois did not represent continuous movement from these states.

On a regional percentage basis, there is only a slight difference between continuity from Missouri or Iowa in cold front and stationary-warm front hailstorms with slightly more than 50 percent of the hailstorms in western Illinois not continuous storms from out-of-state. Air mass and low-trough produced hailstorms in Illinois had even lower frequencies of movement from Iowa and Missouri.

Location and Extent. Measurements of the locations of storm occurrence and the extent of hail incidence on the severe storm days were made. The number of times that hail occurred in each of the 24 state divisions is shown in Figure 5. These numbers include hail occurrences on the days prior to the storm date. To a certain degree, the hail frequencies in Illinois shown on Figure 5 agree with average summer hail pattern in the state.(3) These 128 severe hail days represented between 15 and 55 percent of the total number of hail days at the various stations in Illinois in the 1910-1959 period.

The degree to which the Illinois severe hailstorm activity was restricted to the state is shown by the fact that the division frequencies for 6 of the 9 Illinois divisions are greater than those found in any of the divisions in Iowa or Missouri. Interestingly, the frequencies in the northwestern divisions of Iowa and Missouri (Fig. 1) rank seventh and eighth, respectively, among the 24 divisions. The relatively high frequencies for the divisions whose eastern

borders are more than 100 miles distant from Illinois are a reflection of the high number of occurrences in each of them on the days prioT to the Illinois storm dates. That is, many of these relatively distant hail occurrences were produced by systems which ceased producing hail before entering eastern Missouri and Iowa. However, these systems reformed 12 to 24 hours later in western Illinois to produce severe hailstorms in Illinois. An example of this reformation for one of the severe storm systems is. shown in Figure 6d.

Two measurements of the extent of hail on these 128 hail days were made. One included counts of the number of stations reporting hail; the second was based on a count of the number of divisions reporting hail on individual storm days. In Table 5, the number of divisions with hail on each of the 128 days (plus prior dates) are shown classified by synoptic types. The model number of divisions, the number most frequently observed, was 4 divisions per storm day. The median number of divisions which experienced hail on a storm day was 6 which is 25 percent of the 3-state area. Examination of the frequencies with the synoptic types in Table 5 reveals that the median number of divisions with cold front hailstorms was 6 indicating that these storms had slightly less areal extent than did the hailstorms on days associated with stationary-warm fronts which had a median value of 7 divisions.

The areal extent of the hail incidences on the severe hailstorm days also was measured by counting the number of Weather Bureau stations which reported hail with each storm. This included occurrences on the day prior to

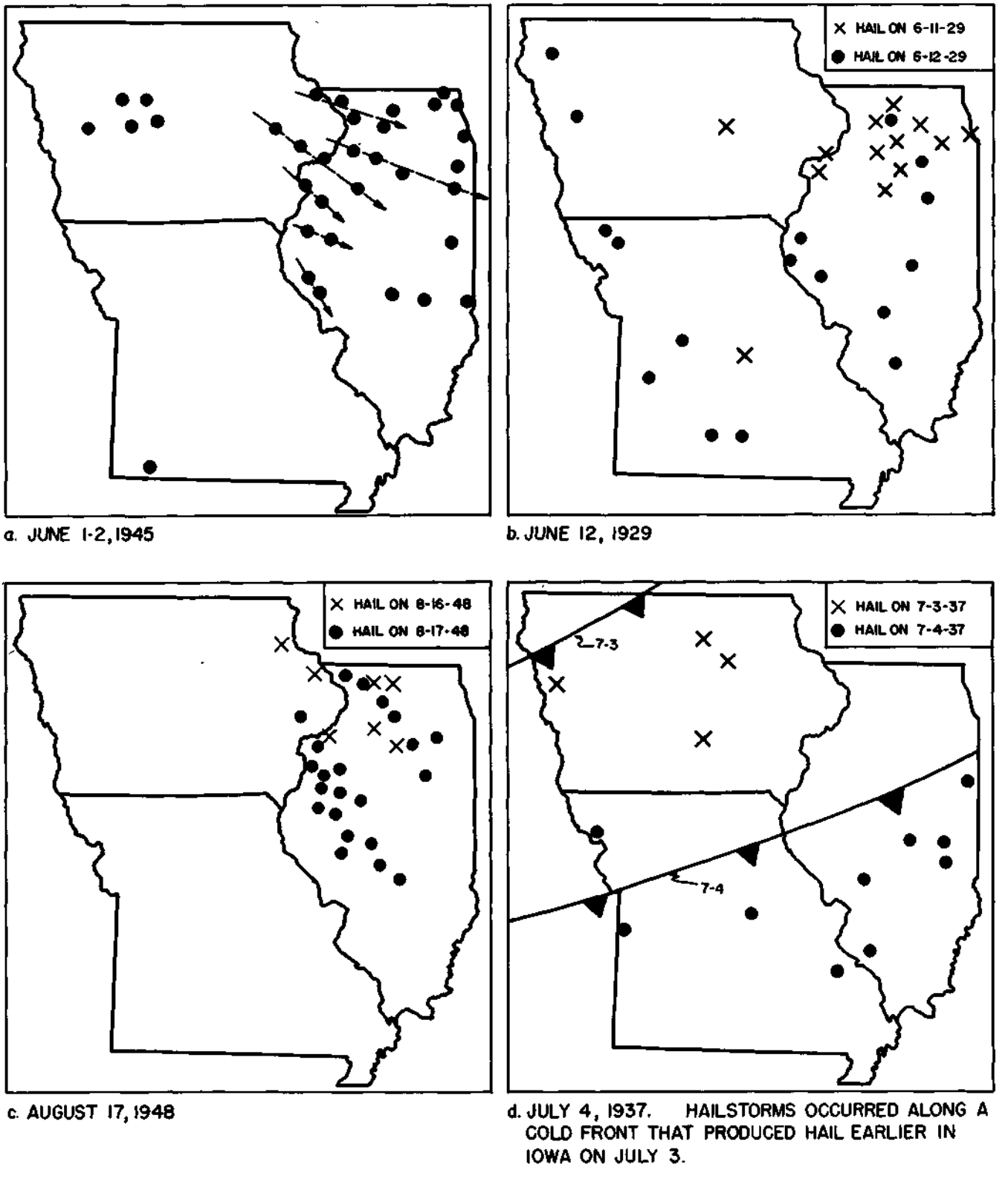
TABLE 5

NUMBER OF STATE DIVISIONS WITH HAIL
PER STORM DAY SORTED BY SYNOPTIC TYPES

Synoptic Types	Number of Divisions with Hail														Totals
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Cold Fronts	1	1	5	14	10	12	13	8	2	5	2	1	0	1	75
Stationary-Warm Fronts	0	1	1	6	3	3	4	4	3	2	1	0	0	1	29
Air Mass	0	3	7	2	3	0	0	1	1	0	0	0	0	0	17
Lows - Troughs	0	1	2	0	2	0	0	1	1	0	0	0	0	0	7
Totals	1	6	15	22	18	15	17	14	7	7	3	1	0	2	128

the severe storm day. The average number of station reports per storm day was found to be 10: normally, 7 of these in Illinois, 2 in Iowa, and 1 in Missouri. An accurate measure of the extensiveness sepresented by these station frequencies is difficult to obtain because the number of hail-reporting stations varied during the 1910-1959 period. In general, the number varied from a low of 125 to a high of 175 stations reporting hail incidences. This meant that the 10-station incidence average per storm period represented about 6 to 8 percent of the total possible stations in the 3-state area.

The greatest number of station reports of hail with one of the severe storms was 34 which occurred on June 1-2, 1945. The map portraying the reports with this storm is shown in Figure 6a. Twenty-five of the 34 reports occurred in Illinois with 8 in Iowa and 1 in Missouri. An example of an extensive



a. JUNE 1-2, 1945

b. JUNE 12, 1929

c. AUGUST 17, 1948

d. JULY 4, 1937. HAILSTORMS OCCURRED ALONG A COLD FRONT THAT PRODUCED HAIL EARLIER IN IOWA ON JULY 3.

FIG.6 EXAMPLES OF HAIL PATTERNS WITH EXTENSIVE SEVERE HAILSTORMS

storm day with reports more widely dispersed throughout the entire 3-state area is shown in Figure 6b. This storm was associated with a stationary front on June 12, 1929. when 21 stations reported hail. Another example of a storm with many reports, but with almost all of the reports concentrated in Illinois, is shown in Figure 6c. This storm which occurred on August 17, 1948, had 26 station hail reports with 23 in Illinois, and was the most damaging hailstorm day ever recorded in Illinois.[2]

Relationship of Severe Hail Days and All Hail Days. Of particular interest to the climatology of hail in Illinois was the relationship of the hail pattern associated with these severe summer hail days to the average pattern based on all summer hail days that occurred during the 1910-1959 period. The state pattern based upon the number of severe hail days at the reliable reporting stations in Illinois is shown in Figure 7. Three notable areas of higher frequencies are apparent. One of these areas of high incidence extends southward from Moline. Another high area is centered on Dixon with an extension southeast to Pontiac and another extension to the east to Chicago. The third area of high incidence is located in central Illinois extending eastward from Jacksonville through Decatur. This third area is separated from the other: high areas by an area of low incidence centered on Peoria.

Comparison of the pattern displayed in Figure 7 with the average summer hail distribution in Illinois (Fig. 2, CHIAA Report No. 11), reveals many similarities and some startling dissimilarities. The major areal difference occurs in the Decatur area. Inspection of the average summer hail distribution

reveals that Decatur is in a region of relatively low incidence, yet it was in an area of high incidence of severe summer hail days (Fig. 7).

A further measure of the relationship of the pattern of severe summer hail days to the pattern based on all summer hail days can be gained by inspection of Figure 8. At each station, the number of severe summer hail days in the 1910-1959 period was expressed as a percent of the total summer hail days, and a percentage pattern was constructed from these data. In the areas of high incidence of severe hail days these hail days are shown to have been more than 40 percent of the total number of summer hail days that occurred in these regions. In areas from Moline eastward and north of Decatur these severe summer hail days represented more than 50 percent of all the summer hail days that occurred during the 1910-1959 period. The area of high incidence in the average summer hail pattern located in the hills of northwestern Illinois [3] was not derived from the severe summer hail days because the percentages in this area are generally less than 25 percent. Similarly, the area of high incidence in all hail days located west of Jacksonville[3] is shown by the low percentages in this area (Fig. 8) derived principally from non-severe hail days.

Storm Durations. Temporal data on the occurrence of hail were too incomplete to permit a detailed analysis of the durations. However, the durations of the storms in the 3-state area were classified as lasting from 0.1 to 12 hours, 12 to 24 hours, or greater than 24 hours. Based upon such an

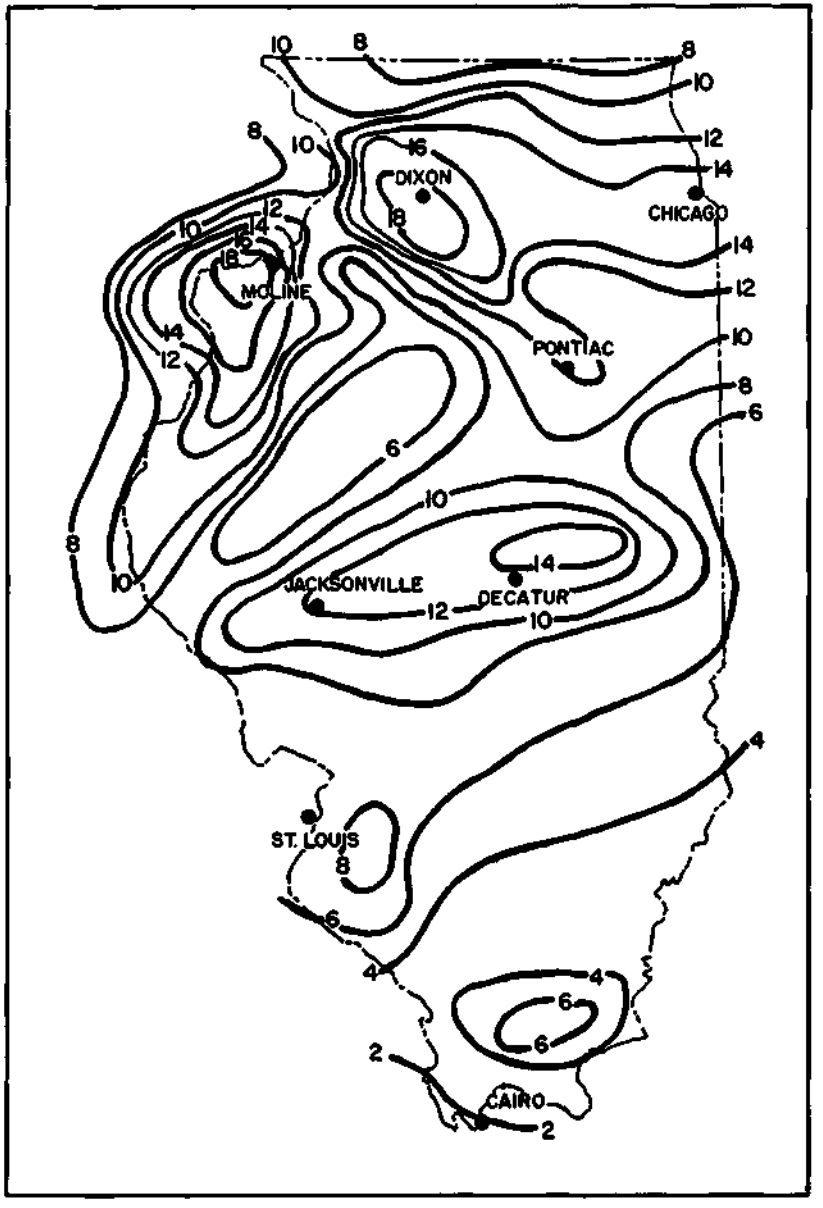


FIG. 7 DISTRIBUTION OF SEVERE HAIL DAYS, 1910-1959. BASED ON NUMBER OF DAYS AT REPORTING STATIONS

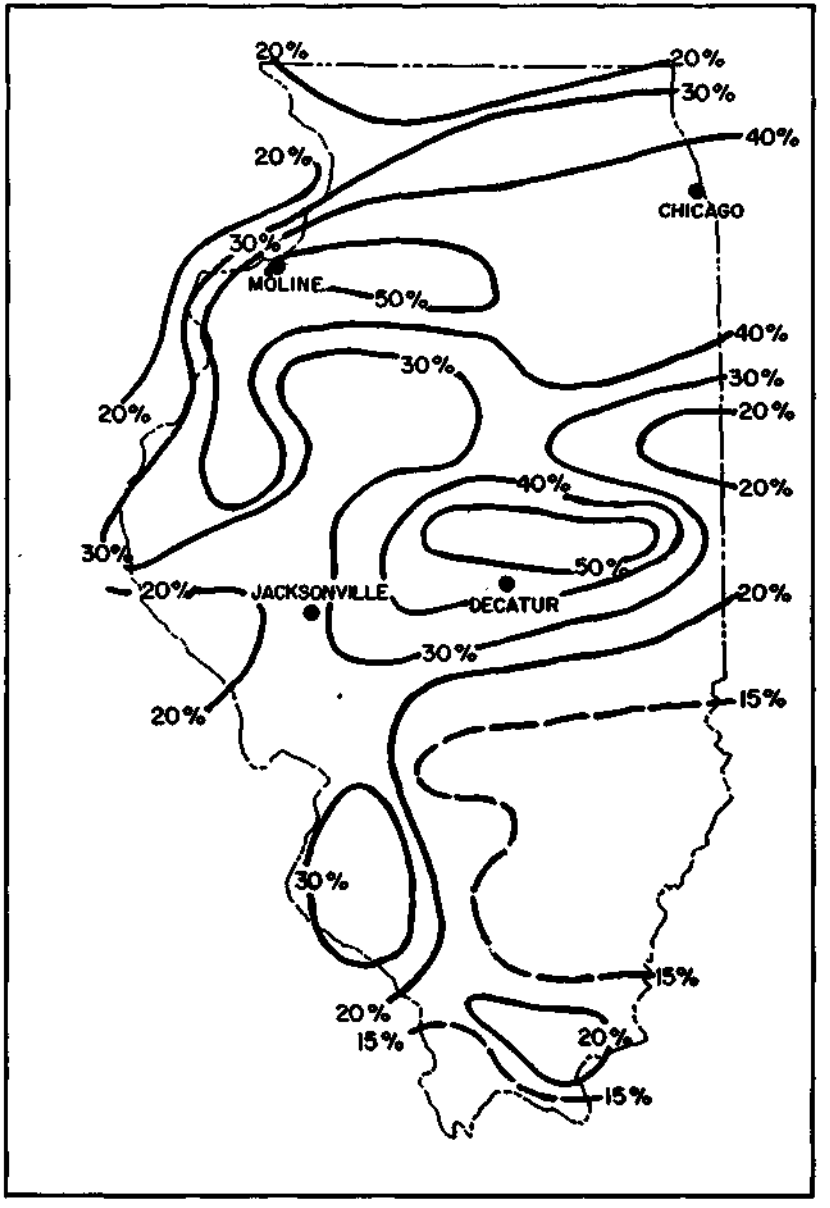


FIG. 8 NUMBER OF SEVERE SUMMER HAIL DAYS EXPRESSED AS PERCENTAGES OF TOTAL HAIL DAYS DURING 1910-1959.

analysis, it was found that 52 of the storm periods had duration of 12 hours or less. There were 43 storm periods with durations ranging from 12 to 24 hours, and 33 periods ranged from 24 to 48 hours in duration.

Summary

The Weather Bureau hail data on the 128 days in the 1910-1959 period with the severest summer hailstorms in Illinois were examined to learn more about the regional characteristics of these storms. More than 80 percent of these single and often multiple storm areas were associated with cold front of stationary-warm front conditions. The number of cold front storms accounted for nearly 60 percent of the 128 storms.

It was found that 68 percent of all hail areas originated in Illinois with 25 percent in Iowa and 7 percent in Missouri. Sixty-four percent of all hail areas originated along the Mississippi River Valley from north of St. Louis to Dubuque, Iowa. On 88 percent of all 128 storm days in Illinois some hail occurred within 30 miles of Iowa and/or Missouri, and yet on 76 percent of these 113 storm days with hail near Iowa or Missouri, the storms did not move from these states. Movement of hailstorms in the major hail areas is most frequent from the west-northwest and northwest. Severe hailstorms produced in warm air mass and low-trough conditions covered less area and had fewer movements from Iowa and Missouri than did the hailstorms with cold fronts and stationary-warm fronts.

On the 128 storm days approximately 70 percent of all hail reports were from stations in Illinois. The median number of state divisions

with hail occurrences per storm was 6, and the six northwesternmost divisions in Illinois experienced hail on these storm days more frequently than any divisions in Missouri and Iowa. Relatively high hail occurrence frequencies in northwestern Missouri and Iowa on or one day prior to these 128 storm days were a result of the fact that 50 percent of the hail-producing storm systems in Illinois had ceased producing hail in eastern Iowa and Missouri after producing hail in the western portions of these states 12 to 36 hours prior to the outbreak of the Illinois hailstorms. Ninety-five of the 128 storm periods had durations in the 3-state area of 24 hours or less.

The number of hail incidences provided by these 128 storm days at Illinois stations varied from 10 to 58 percent of the total number of hail days during the 1910-1959 period. In the Decatur and Moline areas more than 50 percent of all hail days in this 50-year period were severe hail days.

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